Biological Conservation 173 (2014) 17–23

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Short communication

A global gap analysis of sea turtle protection coverage

Antonios D. Mazaris [a,*], Vasiliki Almpanidou [a], Bryan P. Wallace [c,d,e], John D. Pantis [a], Gail Schofield [b]

[a] Department of Ecology, School of Biology, U.P. Box 119, Aristotle University, 54124 Thessaloniki, Greece
[b] Centre for Integrative Ecology, School of Life and Environmental Sciences, Deakin University, Warrnambool, Victoria 3280, Australia
[c] Oceanic Society, 30 Sir Francis Drake Blvd., P.O. Box 437 Ross, CA 9495, USA
[d] Duke University Marine Laboratory, Division of Marine Science and Conservation, 135 Duke Marine Lab Road, Beaufort, NC 98516, USA
[e] Stratus Consulting, 1881 Ninth Street, Suite 201, Boulder, CO, USA

ARTICLE INFO

Article history:
Received 3 December 2013
Received in revised form 18 February 2014
Accepted 4 March 2014
Available online 4 April 2014

Keywords:
Coastal conservation
Global gap analysis
Irreplaceability
Regional effort
Reserve networks
Uncertainty

ABSTRACT

Although the number and extent of protected areas (PAs) are continuously increasing, their coverage of global biodiversity, as well as criteria and targets that underline their selection, warrants scrutiny. As a case study, we use a global dataset of sea turtle nesting sites ($n = 2991$) to determine the extent to which the existing global PA network encompasses nesting habitats (beaches) that are vital for the persistence of the seven sea turtle species. The majority of nesting sites (87%) are in the tropics, and are mainly hosted by developing countries. Developing countries contain 82% nesting sites, which provide lower protection coverage compared to developed countries. PAs encompass 25% of all nesting sites, of which 78% are in marine PAs. At present, most nesting sites in PAs with IUCN ratification receive high protection. We identified the countries that provide the highest and lowest nesting site protection coverage, and detected gaps in species-level protection effort within countries. No clear trend in protection coverage was found in relation to gross domestic product, the Global Peace Index or sea turtle regional management units; however, countries in crisis (civil unrest, war or natural catastrophes) provided slightly higher protection coverage of all countries. We conclude that global sea turtle resilience against threats spanning temperate to tropical regions require representative PA coverage at the species level within countries. This work is anticipated to function as a first step towards identifying specific countries or regions that should receive higher conservation interest by national and international bodies.

1. Introduction

GAP analysis is a quantitative approach that is used to identify gaps in actual and potential systematic conservation planning and coverage (e.g. Scott et al., 1993). The outputs of GAP analyses are based on specific conservation metrics (e.g. percentage of area or species being covered), providing an effective means of identifying unprotected areas of high biodiversity value (Margules and Pressey, 2000; Possingham et al., 2006; Rodrigues et al., 2004a). For instance, several GAP analyses have focused on the extent to which protected areas (PAs) represent species diversity, and in identifying priority regions for the expansion of this global network (e.g. Chape et al., 2005; Rodrigues et al., 2004b). Such studies have demonstrated that biodiversity hotspots are primarily concentrated in tropical regions where countries are more likely to have developing economies (Brooks et al., 2006; Myers et al., 2000). Developing countries also tend to have lower national security (i.e. increased levels of social unrest, war or vulnerability to natural catastrophes) and greater rates of habitat loss compared to wealthier countries (Myers et al., 2000; Sodhi and Ehrlich, 2010). Consequently, the national funds of developing economies are likely to be, logically, diverted towards promoting economic growth and/or mitigating disasters, rather than meeting the needs of conservation efforts (Bruner et al., 2004; James et al., 2001). In turn, wealth is assumed to increase interest (and willingness) to invest in biodiversity conservation (Amano and Sutherland, 2013; Jacobsen and Hanley, 2009). Therefore, objective evaluations of global PA performance should consider the financial capacity, policy mechanisms, quality of scientific knowledge and understanding/experience of conservation needs of countries belonging to wealthy nations versus developing economies (Amano and Sutherland, 2013; Rands et al., 2010). Such information could, therefore, contribute towards identifying specific conservation needs at social, economic, political and ecological levels to maximise the conservation coverage of threatened wildlife (Steiner et al., 2003).

* Corresponding author. Tel.: +30 2310998975; fax: +30 2310 998379.
E-mail addresses: amazaris@bio.auth.gr (A.D. Mazaris), valmpani@bio.auth.gr (V. Almpanidou), wallace@oceanicsociety.org (B.P. Wallace), pantis@bio.auth.gr (J.D. Pantis), g.schof@gmail.com (G. Schofield).

http://dx.doi.org/10.1016/j.biocon.2014.03.005
0006-3207/

The selection of eligible sites and the development of protected-area networks are underpinned by the fundamental goal of ensuring the representation of biodiversity features of high conservation interest (Pressey et al., 1994). Therefore, it is important to establish to what extent existing PA networks protect important habitats (i.e. breeding, foraging or migratory) used by populations of threatened species and, hence, whether the resilience of target species is safeguarded (Heller and Zavaleta, 2009). Sea turtles represent one such group of threatened species (seven species forming a single super-family: loggerhead, *Caretta caretta*, green, *Chelonia mydas*, hawksbill, *Eretmochelys imbricata*, Kemp's ridley, *Lepidochelys kempii*, olive ridley, *Lepidochelys olivacea*, flatback, *Natator depressus*, and leatherback, *Dermochelys coriacea*), which aggregate to breed and nest on the beaches of countries spanning both tropical and temperate regions (latitudinal range: −29°S to 44°N) (IUCN, 2012; Wallace et al., 2011). Edgar et al. (2008) suggested that mapping the location of threatened species that form highly aggregated populations in time or space could be used to systematically identify priority conservation targets. Accordingly, a recent global assessment of sea turtle nesting sites (seven species from two families) delineated spatially and biologically distinct regional management units (RMUs) (Wallace et al., 2010), to provide a framework for the assessment of conservation status and threats (Wallace et al., 2011). Yet, a knowledge gap remains about whether the existing global network of PAs actually safeguards the nesting habitats of the seven sea turtle species; thus, obscuring efforts to delineate effective national or international conservation policies.

The monitoring and conservation efforts of sea turtles are primarily focused on the nesting beaches, because of the relative ease of access and ability to assimilate population level datasets (Hamann et al., 2010; Hopkins-Murphy et al., 2003; Mazaris et al., 2005), compared to more broadly dispersed marine foraging sites to which turtles migrate (e.g. Hawkes et al., 2011; Schofield et al., 2013a,b, but see Scott et al., 2012). While turtles are at high risk of fisheries impact in foraging areas (Lewison et al., 2013; Wallace et al., 2011), threats to nesting habitat are primarily associated with the destruction and loss of beaches, through mechanisms such as coastal development and sea level rise due to climate change (termed coastal squeeze; Fuentes et al., 2012; Mazaris et al., 2009). In addition, poaching and the indigenous use or illegal trade of turtle products (i.e. eggs, meat, carapace) (Koch et al., 2006; Wallace et al., 2011) directly threaten sea turtle population viability and trends in many regions. Yet, many sea turtle nesting beaches remain unprotected, despite the importance of establishing PAs that contribute towards building the resilience of sea turtle populations to these various negative impacts (Fuentes et al., 2013; Hamann et al., 2010; Pike, 2013).

Hundreds of organisations (i.e. non-governmental, research groups, and public citizen groups) are involved in sea turtle monitoring and conservation activities worldwide. This phenomenal effort is exemplified by the Global Sea Turtle Network (http://www.seaturtle.org/) and the State of the World's Sea Turtles database – SWOT (http://seamap.env.duke.edu/swot), in which information about sea turtle nesting activities has been provided by more than 600 different contributors from 130 countries. Here, we used this information to identify whether sea turtle nesting sites are included in the 145,378 national and 28,004 international protected sites established to conserve biological diversity around the world (WDPA, 2013). We identify potential gaps in the spatial conservation of the seven sea turtle species, and determine whether the extent of protection is correlated to the economic status and/or security of each country. We consider this evaluation as a first step toward highlighting conservation needs and feasibility for sea turtles at a global scale.

2. Material and methods

We analysed a total of 2991 georeferenced records of nesting sites used by all seven sea turtle species in 130 countries (or 4402 nesting sites per species, because the nesting sites of several species overlap). Data on the global distribution of sea turtle nesting sites were obtained from state of the World's Sea Turtles database (Halpin et al., 2009; Kot et al., 2013; SWOT Reports volumes I–VII, 2006a,b, 2008, 2009, 2010, 2011, 2012; http://seamap.env.duke.edu/swot). Data on the global distribution of PAs were obtained from the 2013 world database on protected areas (WDPA, 2013). Currently, the database contains distributional maps of about 174000 PAs with different designation status (accessed November 2013). We determined the protection status of PAs for which the IUCN protected areas categories system (I, Ia, Ib, II, III, IV, V, VI) was available, with categories I to IV representing greater levels of restriction (Dudley, 2008).

To identify gaps in the coverage of existing protected sites, we overlaid maps showing the geographical centre of each nesting site (as this was the single parameter consistently provided by all monitoring groups) on a map containing all protected areas around the globe (Fig. 1). ArcGIS (version 9.2, ERSI, 2005) was used to overlay the digital sources. At present, the total size (lengths and widths) of nesting sites and total annual nest numbers of all sites are not available on SWOT; therefore, it was not possible to assess protection coverage in relation to the nesting effort; however, future access to this information would further refine the current analysis. We employed the Chi square test to investigate whether the number of species that visited a given nesting site was related to protection coverage. The Euclidean distance between the centre of each nesting site and the closest edge of the nearest PA was also calculated to demonstrate the proximity of nesting sites to existing PAs.

We first examined the PA coverage of nesting sites at the country-level for all seven species, combined and separately, in relation to the IUCN protected areas category system. Our assessment of species-specific protection coverage at the country level in the results is focused on countries that present the highest and lowest coverage, along with those that are known to host the greatest numbers of nest (http://www.nmfs.noaa.gov/pr/species/turtles). We then analysed the data with respect to (1) tropical, sub-tropical and temperate status, (2) the economic status of the countries, including GDP (3) the presence of existing crises (e.g. civil unrest, wars or natural catastrophes), (4) the regional-level, and (5) sea turtle regional management units (Wallace et al., 2010, 2011).

Tropical, sub-tropical and temperate nations were separated according to the Meteorological Glossary (American Meteorological Society, 2013). Economic status was assessed by grouping each country as developed or developing, according to the classification statutes provided by the United Nations Statistics Division (http://unstats.un.org/unsd/methods/m49/m49regin.htm; assessed November 2013), which are based on economic growth and stability, human wealth, the standard of living and the infrastructure. In addition, the gross domestic product (GDP) per capita was obtained for each country from the World Factbook (2013). A Spearman rank correlation test was used to investigate any potential relationship between GDP per capita and the number of protected and total nesting sites at the country-level.

Information about conflicts was obtained from the 2012 Global Conflict Barometer, published by the Heidelberg Institute for International Conflict Research (HIIK, 2012). Any country that hosts a sea turtle nesting site and is currently under at least one type of violent conflict within its borders was included in this category. Countries that were involved in diplomatic tensions, or had crises outside of their borders, were excluded. For the purposes of this

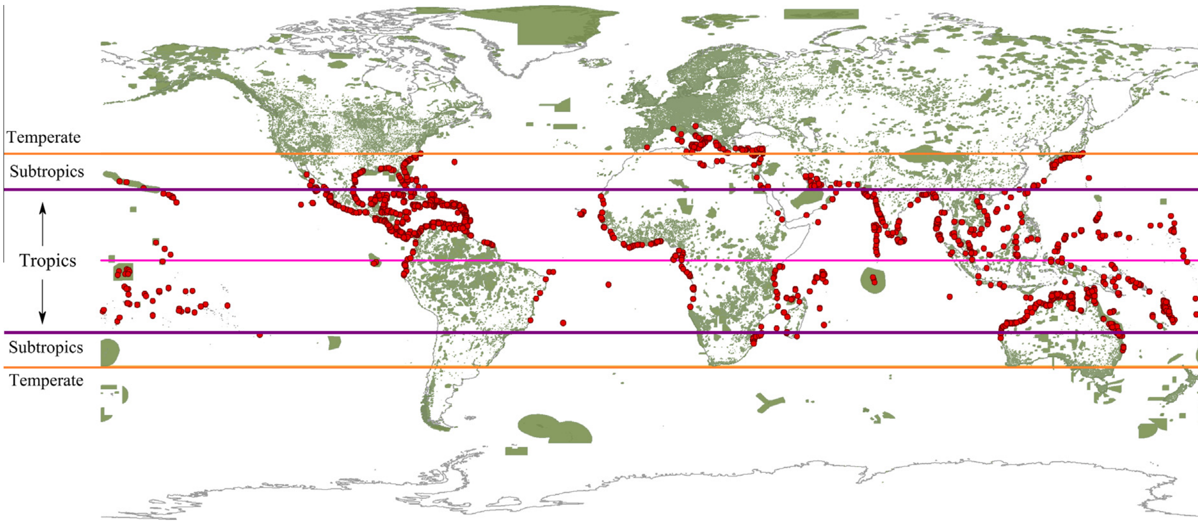

Fig. 1. Global distribution of sea turtle nesting sites (filled red circles) and the location of current protected areas worldwide (green shaded areas). Pink horizontal line = Equator; Purple horizontal lines = Tropics of Cancer and Capricorn (23°7′N and S, respectively), between which the tropics lie; Orange horizontal lines = the 38th parallel in each hemisphere, within which is the subtropics and outside of which is temperate regions. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

study, crises outside a given country's borders were assumed to not affect the ability to administer protected area management or promote conservation efficiency, as it was not possible to objectively quantify this type of issue. The Mann–Whitney test was used to investigate whether the levels of protection were significantly different between countries in crisis and out of crisis. As an additional measure of the level of security in each nation, we used the Global Peace Index (GPI), which combines 22 indicators, such as the degree of militarisation and the relationship with neighbouring countries. This index provides a comprehensive quantification of security, and was derived from a report by the Institute for Economics and Peace (2013) (http://economicsandpeace.org/; assessed November 2013). To investigate any potential association between the GPI, number and protection status of nesting sites per country, we employed the non-parametric Spearman rank correlation coefficient. For the regional-level assessment, we grouped each country into geographical sub-regions, based on the groups provided by the United Nations Statistics Division (http://unstats.un.org/unsd/default.htm; accessed June 2013). Building on the work of Wallace et al. (2010), we also assessed the level of protection coverage of nesting sites by PAs in the different regional management units (RMUs). These units were originally developed as a means of proposing units of protection for geographically distinct sea turtle populations (defined from genetics and demographic information).

3. Results

3.1. PA coverage of nesting sites

We identified a total of 2991 unique nesting sites that host reproductive activity by one to five species of sea turtles. About 32% of these sites were used by two or more sea turtle species. Of all nesting sites, 751 sites (~25%) fall within 343 established PAs. The remaining nesting sites ($n = 2240$) were located at a range of distances from the nearest established PA (Fig. 2). Nesting sites used by loggerheads and flatbacks received the highest protection of all seven sea turtle species, with about 35% of all sites for both species being located within existing PAs (Table 1). The nesting sites that fell within existing PAs for the other five species ranged from 19.6% to 27.1%. The inclusion or exclusion of nesting sites within PAs was not associated with the number of sea turtle species hosted by each site ($p > 0.05$).

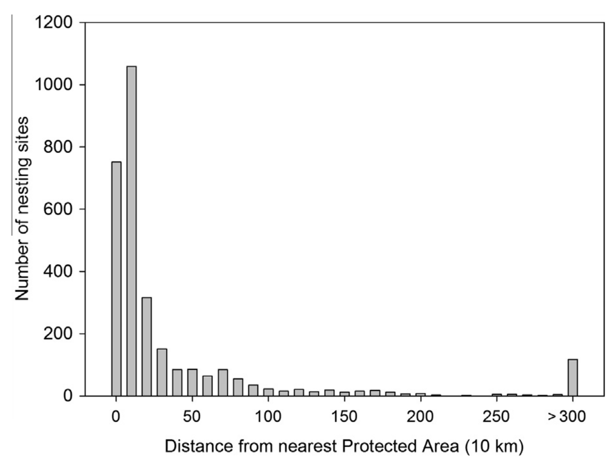

Fig. 2. Number of sea turtle nesting sites located within and outside PAs using 10 km bins.

Almost 80% of the PAs that contain nesting sites are listed as marine protected areas (MPAs), under various IUCN management categories. The remaining sites fell under the protection of various terrestrial reserves. For each sea turtle species, from 50% to 86% of PAs containing nesting sites are listed as MPAs, except flatback sites, of which 32% PAs were MPAs. Data from the IUCN protected areas categories system were available for 57% of the PAs containing nesting sites, of which 71% were assigned as IUCN I–IV sites (i.e. strict protection). At the species-level, about 42% of Kemp's ridley sites received strict protection, while for other species this value ranged between 62% and 89% of the nesting sites (Table 1).

3.2. Country-level protection

Supplementary Table A1 lists all of the countries containing nesting sites, and identifies the countries that provide the highest and lowest protection of species. Of concern, Vanuatu only protects 2% of its nesting sites; yet, supports the fourth greatest number of

Table 1
Number of sea turtle nesting sites per species and the percentage of these sites that is enclosed within protected areas (PAs) based on the 2013 world database on protected areas (WDPA, 2013). The total number of unique nesting sites analysed in the present study is 2991; this table presents number of sites visited by each species with several species overlapping the same sites. The percentage of nesting sites that are enclosed by PAs that receive strict conservation (IUCN categories I–IV) and the percentage of PAs that host nesting sites and are listed as marine protected areas (MPA).

Species	Nesting site	% of sites that receive protection	% of sites that receive strict protection	% of PAs listed as MPAs
Caretta caretta	564	35.11	62.96	77.36
Chelonia mydas	1170	27.09	69.23	85.96
Dermochelys coriacea	661	21.33	63.75	79.75
Eretmochelys imbricata	1346	24.15	70.93	84.87
Lepidochelys kempii	43	23.26	42.86	50.00
Lepidochelys olivacea	419	19.57	89.13	86.00
Natator depressus	201	33.83	70.21	3200

total nesting sites ($n = 180$ sites). This country hosts the nesting sites of five turtle species, with the highest number of green ($n = 157$ sites) and hawksbill ($n = 123$) sites compared to all countries. India only protects 4% of its nesting sites, hosting the third greatest number of total sites (after Mexico and Australia); yet, it has the greatest number of olive ridley ($n = 106$) nesting sites, third greatest number of hawksbill nesting sites ($n = 61$), and fifth greatest number of green ($n = 41$) and leatherback ($n = 29$) nesting sites. Although a significant increase in global coverage could be achieved by increasing the contribution of most countries, assessment of the datasets indicate that greater benefit (global) would be obtained by focusing on nations that currently offer lower protection coverage (>20%) (Fig. 3).

The USA (Florida), Oman and Cape Verde are known to have the largest numbers of nesting loggerhead sea turtles; yet, only the USA provides protection coverage (35% versus 0% and 0% respectively). Australia contains major green, hawksbill and flatback nesting numbers, but provides variable protection levels for these three species (60%, 22% and 34% respectively). Costa Rica also hosts major green turtle populations, providing 33% protection coverage of this species' nesting sites. Mexico provides highly variable protection coverage, despite supporting major nesting numbers of three out of five species. For instance, it supports major olive ridley and hawksbill nesting numbers, yet provides 11% and 62% protection coverage, respectively. In addition, it supports 95% of all Kemp's ridley nesting effort, but provides just 28% protection coverage for this species. India also supports major olive ridley nesting numbers, and also provides very low protection coverage (4%). French Guiana and Gabon host the largest leatherback nesting activity, and both provide high protection coverage (75% and 60%).

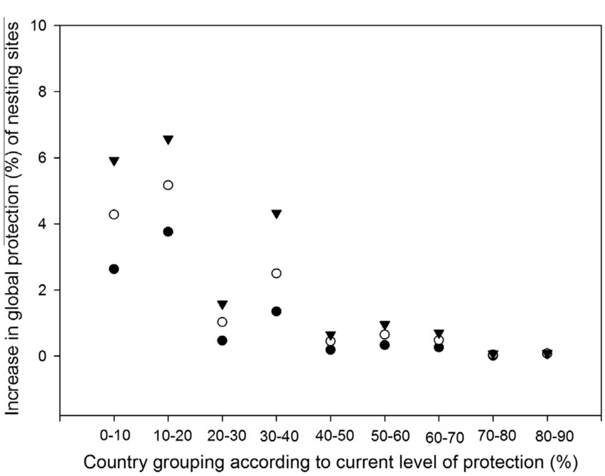

Fig. 3. Theoretical increase in current global sea turtle nesting site coverage by PAs based on three levels of protection increment. The counties were grouped into nine classes based on the current level of protection being offered (0–10%, 10–20%, etc.). The increase in coverage was estimated for each group once the current level of protection was increased by 10 (black dots), 15 (open dots) and 20% (triangles) in each country. For instance, if countries that currently provide 0–10% protection were to increase their protection coverage by 20%, global protection would be enhanced by 6%.

3.3. Developed versus developing countries

Overall, 87% of nesting sites were in the tropical zone, and are mainly hosted by developing countries (Fig. A2). Countries with developed economies contained 532 nesting sites (18% of all sites), of which 38% are afforded protection by PAs. Countries listed as developing economies contained 2459 nesting sites, of which 22% are afforded protection by PAs. The GDP per capita (as a metric of wealth) was marginally, but significantly, related to the number of nesting sites at the country level ($rs = 0.18$, $p < 0.05$), but not to the protection of the sites ($p > 0.05$). More than 37% of sea turtle nesting sites globally are located in countries that are experiencing some type of crisis (47 out of 130 countries). These countries provided greater protection coverage of nesting sites (28%) compared to countries not facing a crisis (28% versus 22%, respectively); although this difference was not statistically significant ($p > 0.05$). The Global Peace Index metric was available for about half of the countries containing sea turtle nesting sites; however no significant association was found for this index in relation to the total number of nesting sites or the percentage of these sites located within PAs (in both cases $p > 0.05$).

3.4. Regional-level analyses

There were noticeable regional differences in the extent to which sea turtle nesting sites were included in PAs (Fig. 3). For example, PAs containing nesting sites were afforded the greatest protection in Northern America (34% in PAs, $n = 114$), followed by Europe (28%, $n = 61$), Africa (27%, $n = 238$) and Latin America and the Caribbean (27% in PAs, n = 1365). In comparison, nesting sites in Oceania (24%, $n = 711$) and Asia (18%, $n = 502$) receive the least protection.

The protection coverage given to each sea turtle species in each sea turtle RMU varied significantly, with no clear trend (Fig. 4; Fig. A1). The RMUs of loggerheads, greens and hawksbills received moderate to high level protection coverage along the eastern coast of North America. In comparison, leatherbacks and greens received higher protection in the South African nesting sites. The protection coverage of the 10 RMUs in Australia (which hosts the nesting sites of six out of the seven species) varied; loggerheads and greens received high protection, leatherbacks and hawksbills received low to moderate protection, while flatbacks received low to high levels of protection.

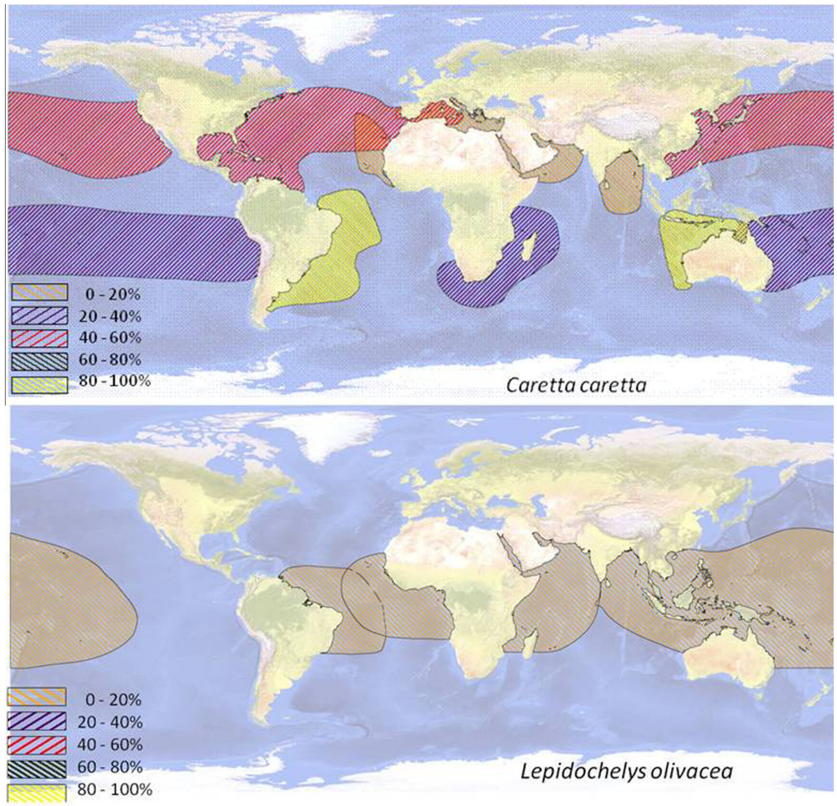

Fig. 4. Two examples of the percentage of nesting sites that fall within existing protected areas in each sea turtle Regional Management Unit (Wallace et al., 2010): (a) loggerheads (with temperate to sub-tropical nesting sites), which receive low to high levels of protection the various RMUs and (b) olive ridleys (with tropical nesting sites), which receive consistently low protection levels in all RMUs. Please see Supplementary Fig. 1A presenting this information for each of the seven sea turtle species.

4. Discussion

Here, we verified that the coverage of the existing PA network is inadequate for sea turtle nesting sites at a global scale. Most nesting sites are located in the tropics, of which most are in developing countries where lower protection coverage is provided compared to wealthy countries. In addition, certain species receive higher and stricter protection in certain countries. Using this information, we identified the countries that provide the highest and lowest protection coverage, and considered how national protection coverage could be enhanced to improve the global resilience of the seven sea turtle species.

Only a quarter of sea turtle nesting sites globally are currently encompassed within PAs, confirming the importance of identifying gaps in existing protection effort. Agardy et al. (2011) observed that poor designation processes underpinning the design and establishment of PAs cause major obstacles for efficiency. Hence, careful consideration of these parameters is required at the national level for sea turtles globally, particularly with respect to the degree of protection being provided. We found that most nesting sites within PAs had high IUCN protection ratings, so it is likely that the conservation of sea turtles has played an important role in the establishment of many of these sites (e.g. Great Barrier Reef National Park, Australia, Wilson and Tisdell, 2001; Zakynthos, Greece, Schofield et al., 2013b). In contrast, the nesting sites of the Kemp's ridley receive the lowest level of protection globally in IUCN rated PAs (just 43%), demonstrating a clear gap in the protection effort of this species that requires resolving. Yet, while some regions may be classified as PAs, protection measures may not exist or may not be enforced for various reasons, such as lack of resources or management agency (e.g. Bonham et al., 2008). In contrast, nesting sites may receive effective protection in regions that are not listed in the WDPA (2013) classification system, via governmental legislation, local voluntary initiatives, or due to their falling within military bases (including various sites in the USA and Ascension Island). Therefore, it is important to obtain information about the protection measures provided to all sea turtle nesting sites globally, to quantify the effectiveness of existing measures, and determine whether sites that fall within PAs receive higher levels of protection. Ultimately, the effective conservation and management of sea turtle reproductive habitats represents a basic global priority (Hamann et al., 2010).

PA networks represent an important tool for protecting species; therefore, they should be representative, with conservation targets being set accordingly (Chape et al., 2005). Yet, tropical and developing nations have been shown to have lower capacities to implement protective legislation compared to wealthy countries (Amano and Sutherland, 2013; Jacobsen and Hanley, 2009; James et al., 2001; Myers et al., 2000), which was also confirmed for sea turtle nesting sites the current study. We showed that the global protection of nesting sites would be noticeably enhanced by improving the PA networks of developing countries, which contain the most sea turtle nesting sites. However, "representativeness" is viewed as an important parameter for biodiversity conservation; hence, even though wealthy countries only contain a fifth of all sea turtle nesting sites, it might be more important to protect a cross-section of nesting sites across tropical and temperate regions to reduce the vulnerability of nesting grounds to various global factors, including climate change (Parmesan and Yohe, 2003). Therefore, the example of international conventions could be followed, whereby a certain percentage of a given geographical area in each nation is set aside for conservation purposes (Noss, 1996; UNWCED, 1987). Although, the effectiveness of this type of approach remains subject to debate because there is variation in the conservation value and needs of species and habitats (Soule and Sanjayan, 1998).

Of importance, the political, economic and social status (i.e. level of crises) of developing countries might impede, even, minimal increases in percentage PA coverage (Amano and Sutherland, 2013; Ban et al., 2012). Unstable social structures are typically associated with environmental degradation and detrimental effects on wildlife and wildlife habitats (Dudley et al., 2002). In addition, wealthy countries have been shown to exhibit a greater interest (and willingness) to invest in biodiversity conservation (Amano and Sutherland, 2013; Jacobsen and Hanley, 2009), whereas many developing countries still rely on sea turtles for cultural or economic purposes, such as consuming the meat and eggs, and selling them for income. (Campbell, 1998; Wilson and Tisdell, 2001). Consequently, these issues present major obstacles to the realisation of sea turtle conservation priorities at a global scale, and the current attempt to shift from the protection of distinct locations to the conservation of regional management units (Hamann et al., 2010; Wallace et al., 2010, 2011). It has been suggested that education and awareness programs might act as low cost alternatives towards reducing pressure on this group of threatened species in countries that have low protection coverage, with working examples of such schemes existing in Indonesia and Papua New Guinea (Ferraro and Gjertsen, 2009). However, such programs are usually only effective if local and governmental support/acceptance is obtained (Brockington, 2004; Wells and McShane, 2004). Another alternative is to expand the area represented by existing PAs (Rodrigez et al., 2004b). Yet, we found that this strategy would only be feasible for leatherbacks, with more than 45% of nesting sites occurring within 10 km of existing PAs. In contrast, just 25% of unprotected flatback nesting sites fall within this 10 km range. Furthermore, the expansion of some sites is not possible due to coastal squeeze effects (Mazaris et al., 2009) and socioeconomic issues, along with the adjustment in the placement of existing sites being rather complicated, time consuming and controversial process (Margules and Pressey, 2000; Moffett and Sarkar, 2006). Another option is to base conservation targets based on species ranges (Rodrigues et al., 2004b), but our evaluation of PA coverage in relation to global sea turtle RMUs, which are based on species ranges (Wallace et al., 2010, 2011), did not produce any clear trends. Ultimately, there appears to be no single technique to enhance the global protection of species of biodiversity importance at present, with a variety of options being available that have both benefits and drawbacks.

In our study, we focused on presenting the actual gaps detected in the protection of sea turtle nesting sites, rather than adapting a pre-defined methodology, which we anticipated would produce contradictory outputs (Justus et al., 2008). For instance, Vimal et al. (2011) tested various targets at the species level, and concluded that an applied target scheme significantly influenced the outputs of the analyses. It is critical to set appropriate conservation targets (Vimal et al., 2011); however, to delineate targets that would provide effective protection, detailed (and comparable) ecological information is required for all sites being considered (e.g. population trends and dynamics, abundance, threats, extent to which protection measures are actually implemented, etc.) (Wiersma and Nudds, 2006). Recent studies have highlighted the limitations of using threat maps or hotspot approaches to guide conservation actions (Mace et al., 2000; Wilson et al., 2006; Game et al., 2013). For this reason, the hotspot approach used in the current study incorporated the feasibility of management through the GDP/crisis information. Sea turtle nesting sites require protection because beaches are vulnerable to natural and anthropogenic threats, which might potentially reduce the resilience of this group of species, along with their ability to recover negative impacts (Margules and Pressey, 2000; Possingham et al., 2006; Fuentes et al., 2013). Furthermore, PAs alone may not be the most effective management strategy for safeguarding sea turtle populations, but could represent a tool that, in conjunction with other management strategies (such as those recommended by Fuentes et al., 2012; including regulating coastal development and fishery bycatch), could help build the resilience of existing and potential nesting grounds. Therefore, the results of this work are anticipated to function as a first step towards identifying specific countries and regions that should receive higher conservation interest by national and international bodies. In conclusion, this study provides baseline information about the vulnerability of the nesting populations on which future explicit conservation targets for sea turtles could be developed.

This study aimed to quantify the level of current protection and identify the gaps in conservation, which could help us to draw up effective plans towards mitigating the impacts of climate change and habitat loss on this unique group of organisms. The analysis was based on data kindly provided to SWOT by numerous researchers working on the field around the globe. Hence, this database is dependent on individual users being willing to share information; therefore, it is unlikely that all nesting sites have been identified, with information about the level of nesting at many sites remaining incomplete. Consequently, the country level data of some countries might be skewed, for instance by some countries only listing sites that are protected or sites with major nesting activity. We, therefore, stress that the current information status presented by this work should be regularly updated, and hope that this first analysis could serve as a benchmark for improving conservation, monitoring and international policy efforts of the seven sea turtle species.

Acknowledgments

We gratefully acknowledge the research and the administration of the Project "The State of the World's Sea Turtles (SWOT)" and the numerous data contributors. We thank the anonymous reviewers of this manuscript for their constructive suggestions, along with Graeme C Hays for invaluable suggestions.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biocon.2014.03.005.

References

Agardy, T.M., Notarbartolo di Sciara, G., Christie, P., 2011. Mind the gap: addressing the shortcomings of marine protected areas through large scale marine spatial planning. Mar. Policy 35, 226–232.

Amano, T., Sutherland, W.J., 2013. Four barriers to the global understanding of biodiversity conservation: wealth, language, geographical location and security. Proc. Roy. Soc. B – Biol. Sci. 280, 20122649.

American Meteorological Society, 2013. Glossary of meteorology. <http://glossary.ametsoc.org/wiki/"term">.

Ban, N.C., Cinner, J.E., Adams, V.M., et al., 2012. Recasting shortfalls of marine protected areas as opportunities through adaptive management. Aquat. Conserv. 22, 262–271.

Bonham, C., Sacayon, E., Tzi, E., 2008. Protecting imperiled "paper parks": potential lessons from the Sierra Chinajá. Guatemala. Biodivers. Conserv. 17, 1581–1593.

Brockington, D., 2004. Community conservation, inequality and injustice: myths of power in protected area management. Conserv. Soc. 2, 411–432.

Brooks, T.M., Mittermeier, R.A., da Fonesca, G.A.B., Gerlach, J., Hoffman, M., Lamoreux, J.F., Mittermeier, C.G., Pilgrim, J.D., Rodruigues, A.S.L., 2006. Global biodiversity conservation priorities. Science 313, 58–61.

Bruner, A.G., Gullison, R.E., Balmford, A., 2004. Financial costs and shortfalls of managing and expanding protected-area systems in developing countries. Conserv. Biol. 54, 1119–1126.

Campbell, L.M., 1998. Use them or lose them? conservation and the consumptive use of marine turtle eggs at Ostional, Costa Rica. Environ. Conserv. 4, 305–319.

Chape, S., Harrison, J., Spalding, M., Lysenko, I., 2005. Measuring the extent and effectiveness of protected areas as an indicator for meeting global biodiversity targets. Philos. Trasn. Roy. Soc. B 360, 443–455.
Dudley, N. (Ed.), 2008. Guidelines for Applying Protected Area Management Categories. IUCN, Gland, Switzerland, p. 86.
Dudley, J.P., Ginsberg, J.R., Plumptre, A.J., Hart, J.A., Campos, L.C., 2002. Effects of war and civil strife on wildlife and wildlife habitats. Conserv. Biol. 16, 319–329.
Edgar, G.J., Langhammer, P.F., Allen, G., Brooks, T.M., Brodie, J., Crosse, W., De Silva, N., Fishpool, L.D.C., Foster, M.N., Knox, D.H., McCosker, J.E., McManus, R., Millar, A.J.K., Mugo, R., 2008. Key biodiversity areas as significant target sites for the conservation of marine biological diversity. Aquat. Conserv. 18 (6), 969–983.
ESRI, 2005. ArcView 3.2 Software. Environmental Systems Research Institute, Redlands, CA.
Ferraro, P.J., Gjertsen, H., 2009. A global review of incentive payments for sea turtle conservation. Chel. Conserv. Biol. 8 (1), 48–56.
Fuentes, M.M.P.B., Fish, M.R., Maynard, J.A., 2012. Management strategies to mitigate the impacts of climate change on sea turtle's terrestrial reproductive phase. Mitig. Adapt. Strateg. Glob. Change 17, 51–63.
Fuentes, M.M.P.B., Pike, D.A., Dimatteo, A., Wallace, B.P., 2013. Resilience of marine turtle regional management units to climate change. Glob. Change Biol. 19, 1399–1406.
Game, E.T., Kareiva, P., Possingham, H.P., 2013. Six common mistakes in conservation priority setting. Conserv. Biol. 27, 480–485.
Halpin, P.N., Read, A.J., Fujioka, E., et al., 2009. OBIS-SEAMAP the world data center for marine mammal, sea bird, and sea turtle distributions. Oceanography 22, 104–115.
Hamann, M., Godfrey, M.H., Seminoff, J., et al., 2010. Global research priorities for sea turtles: informing management and conservation in the 21st century. Endanger. Species Res. 11, 245–269.
Hawkes, L.A., Witt, M.J., Broderick, A.C., Coker, J.W., Coyne, M.S., Dodd, M., Frick, M.G., Godfrey, M.H., Griffin, D.B., Murphy, S.R., Murphy, T.M., Williams, K.L., Godley, B.J., 2011. Home on the range: spatial ecology of loggerhead turtles in Atlantic waters of the USA. Divers. Distrib. 17, 624–640.
Heller, N.E., Zavaleta, E.S., 2009. Biodiversity management in the face of climate change: a review of 22 years of recommendations. Biol. Conserv. 142, 14–32.
HIIK, 2012. Heidelberg Institute for International Conflict Research. Conflict Barometer 2012.
Hopkins-Murphy, S.R., Owens, D.W., Murphy, T.M., 2003. Chapter 5: ecology of immature loggerheads on foraging grounds and adults in internesting habitat in the Eastern United States. In: Bolton, A.B., Witherington, B.E. (Eds.), Loggerhead Sea Turtles. Smithsonian Institution, Washington and London, pp. 79–82.
Institute for Economics and Peace, 2013. Global Peace Index 2013. Sydney, Australia: Institute for Economics and Peace.
Jacobsen, J.B., Hanley, N., 2009. Are there income effects on global willingness to pay for biodiversity conservation? Environ. Resour. Econ. 43, 137–160.
James, A., Gaston, K.J., Balmford, A., 2001. Can we afford to conserve biodiversity? Bioscience 51, 43–52.
Justus, J., Fuller, T., Sarkar, S., 2008. The influence of representation targets on the total area of conservation area networks. Conserv. Biol. 22, 673–682.
Koch, V., Nichols, W.J., Peckham, H., de la Toba, V., 2006. Estimates of sea turtle mortality from poaching and bycatch in Bahia Magdalena, Baja California Sur, Mexico. Biol. Conserv. 128, 327–334.
Kot, C.Y., DiMatteo, A., Fujioka, E., et al., 2013. The state of the World's Sea Turtles online database: data provided by the SWOT team and hosted on OBIS-SEAMAP. In: Oceanic Society, Conservation International, IUCN Marine Turtle Specialist Group (MTSG), and Marine Geospatial Ecology Lab, Duke University. <http://seamap.env.duke.edu/swot>.
Lewison, R., Wallace, B., Alfaro-Shigueto, J., et al., 2013. Fisheries bycatch of marine turtles: lessons learned from decades of research and conservation. In: Wyneken, J., Lohmann, K.J., Musick, J.A. (Eds.), The Biology of Sea Turtles, vol. III. CRC Press, Boca Raton, USA, pp. 329–352.
Mace, G.M., Balmford, A., Boitani, L., et al., 2000. It's time to work together and stop duplicating conservation efforts. Nature 405, 393.
Margules, C.R., Pressey, R.L., 2000. Systematic conservation planning. Nature 405, 243–253.
Mazaris, A.D., Fiksen, O., Matsinos, Y.G., 2005. Using an individual-based model for assessment of sea turtle population viability. Popul. Ecol. 47, 179–191.
Mazaris, A.D., Matsinos, G., Pantis, J.D., 2009. Evaluating the impacts of coastal squeeze on sea turtle nesting. Ocean Coast. Manage. 52, 139–145.
Moffett, A., Sarkar, S., 2006. Incorporating multiple criteria into the design of conservation area networks: a mini review with recommendations. Divers. Distrib. 12, 125–137.
Myers, N., Mittermeier, R.A., Mittermeier, C.G., Fonseca, G.A.B., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403, 853–858.
Noss, R., 1996. Protected Areas—How Much is Enough? National Parks and Protected Areas: Their Role in Environmental Protection. Blackwell Science, Cambridge.
Parmesan, C., Yohe, G., 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421, 37–42.
Pike, A.D., 2013. Forecasting range expansion into ecological traps: climate-mediated shifts in sea turtle nesting beaches and human development. Glob. Change Biol. 19, 3082–3092.
Possingham, H.P., Wilson, K.A., Andelman, S.J., Vynne, C.H., 2006. Protected areas: goals, limitations, and design. In: Groom, M.J., Meffe, G.K., Ronald Carroll, C. (Eds.), Principles of Conservation Biology. Sinauer Associates, Sunderland, Massachusetts.
Pressey, R.L., Johnson, I.R., Wilson, P.D., 1994. Shades of irreplaceability: towards a measure of the contribution of sites to a reservation goal. Biodiv. Conserv. 3, 242–262.
Rands, M.R.W., Adams, W.M., Bennun, L., Butchart, S.H.M., Clements, A., Coomes, D., Entwistle, I., Hodge, I., Kapos, V., Scharlemann, J.P.W., Sutherland, W.J., Vira, B., 2010. Biodiversity conservation: challenges beyond 2010. Science 329, 1298–1303.
Rodrigues, A.S.L., Andelman, S.J., Bakarr, M.I., Boitani, L., Brooks, T.M., Cowling, R.M., Fishpool, L.D.C., da Fonseca, G.A.B., Gaston, K.J., Hoffmann, M., Long, J.S., Marquet, P.A., Pilgrim, J.D., Pressey, R.L., Schipper, J., Sechrest, W., Stuart, S.N., Underhill, L.G., Waller, R.W., Watts, M.E.J., Yan, X., 2004a. Effectiveness of the global protected area network in representing species diversity. Nature 428 (6983), 640–643.
Rodrigues, A.S.L., Akcakaya, H.R., Andelman, S.J., Bakarr, M.I., Boitani, L., Brooks, T.M., Chanson, J.S., Fishpool, L.D.C., Da Fonseca, G.A.B., Gaston, K.J., Hoffmann, M., Marquet, P.A., Pilgrim, J.D., Pressey, R.L., Schipper, J., Sechrest, W., Stuart, S.N., Underhill, L.G., Waller, R.W., Watts, M.E.J., Yan, X., 2004b. Global gap analysis: priority regions for expanding the global protected-area network. Bioscience 54, 1092–1100.
Schofield, G., Dimadi, A., Fossette, S., Katselidis, K.A., Koutsoubas, D., Lilley, M.K.S., Luckman, A., Pantis, J.D., Karagouni, A.D., Hays, G.C., 2013a. Satellite tracking large numbers of individuals to infer population level dispersal and core areas for the protection of an endangered species. Divers. Distrib. 19 (7), 834–844.
Schofield, G., Scott, R., Dimadi, A., Fossette, S., Katselidis, K.A., Koutsoubas, D., Lilley, M.K.S., Pantis, J.D., Karagouni, A.D., Hays, G.C., 2013b. Evidence based marine protected area planning for a highly mobile endangered marine vertebrate. Biol. Conserv. 161, 101–109.
Scott, J.M., Davs, F., Csuti, B., Noss, R., Butterfield, B., Groves, C., Anderson, H., Caicco, S., Derchia, F., Edwards, T.C., Ulliman, J., Wright, R.G., 1993. Gap analysis: a geographic approach to protection of biological diversity. Wildlife Monogr. 123, 1–41.
Scott, R., Hodgson, D.J., Witt, M.J., Coyne, M.S., Adnyana, W., Blumenthal, J.M., Broderick, A.C., Canbolat, A.F., Catry, P., Ciccione, S., Delcroix, E., Hitipeuw, C., Luschi, P., Pet-Soede, L., Pendoley, K., Richardson, P.B., Rees, A.F., Godley, B.J., 2012. Global analysis of satellite tracking data shows that adult green turtles are significantly aggregated in marine protected areas. Glob. Ecol. Biogeogr. 21 (11), 1053–1061.
Sodhi, N.S., Ehrlich, P.R. (Eds.), 2010. Conservation Biology for All. Oxford University Press, Oxford, UK.
Soule, M.E., Sanjayan, M.A., 1998. Ecology-conservation targets: do they help? Science 279 (5359), 2060–2061.
Steiner, A., Kimball, L.A., Scanlon, J., 2003. Global governance for the environment and the role of multilateral environmental agreements in conservation. Oryx 37, 227–237.
SWOT, State of the World's Sea Turtles, Reports vol. I-VII. (2006a, 2006b, 2008, 2009, 2010, 2011, 2012). <http://seaturtlestatus.org/>. Assessed 11 July 2013.
United Nations World Commission on Environment and Development, 1987. Our Common Future. Oxford University Press, Oxford.
Vimal, R., Rodrigues, A.S.L., Mathevet, R., Thompson, J.D., 2011. The sensitivity of gap analysis to conservation targets. Biodivers. Conserv. 20, 531–543.
Wallace, B.P., DiMatteo, A.D., Hurley, B.J., et al., 2010. Regional management units for marine turtles: a novel framework for prioritizing conservation and research across multiple scales. PLoS One 5, e15465.
Wallace, B.P., DiMatteo, A.D., Bolten, A.B., et al., 2011. Global conservation priorities for marine turtles. PLoS One 6, e24510.
WDPA, 2013. World Database of Protected Areas.
Wells, M.P., McShane, T.O., 2004. Integrating protected area management with local needs and aspirations. AMBIO 33, 513–519.
Wiersma, Y.F., Nudds, T.D., 2006. Conservation targets for viable species assemblages in Canada: are percentage targets appropriate? Biodivers. Conserv. 15 (14), 4555–4567.
Wilson, C., Tisdell, C., 2001. Sea turtles as a non-consumptive tourism resource especially in Australia. Tourism Manage. 22, 279–288.
Wilson, K.A., McBride, M.F., Bode, M., Possingham, H.P., 2006. Prioritizing global conservation efforts. Nature 440, 337–340.
World Factbook 2013–14. Washington, DC: Central Intelligence Agency, 2013. <https://www.cia.gov/library/publications/the-world-factbook/index.html>.